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ABSTRACT

This study examines the Wheatley Cube as a measure of spatial/visualization ability. The Wheatley Cube is a computer managed task which requires the subject to visualize a three-dimensional workspace and to find an invisible dot located within this space. Thirty-three undergraduate students were administered four tests of spatial/imaginal ability and the scores were correlated with performance measures on the Wheatley Cube task. Significant correlations were observed after subjects had adapted to the Cube Task. A second experiment extending the number of trials on the cube and employing three different spatial tests produced inconsistent results. Modifications of the Wheatley Cube procedure are discussed and specific suggestions for future validity studies are offered. (Author)

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The Wheatley Cube as a Performance Measure of Spatial Visualization

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Abstract

This study examines the Wheatley Cube as a measure of spatial/visualization ability. The Wheatley Cube is a computer managed task which requires the subject to visualize a three-dimensional work space and to find an invisible dot located within this space. Thirty-three undergraduate students were administered four tests of spatial/imaginal ability and the scores were correlated with performance measures on the Wheatley Cube task. Significant correlations were observed after subjects had adapted to the Cube Task. A second experiment extending the number of trials on the cube and employing three different spatial tests produced inconsistent results. Modifications of the Wheatley Cube procedure are discussed and specific suggestions for future validity studies are offered.

Purpose

Egan (1982) suggests that spatial ability is second in importance only to verbal ability for learning, problem solving and job performance. Chase and Simon (1973), noting the immediate perceptual processing of chess positions by chess masters comment, "...it is for good reason that students of complex problem solving are interested in perceptual processes" (p. 56). Indeed, spatial ability is related to mathematical achievement (Hills, 1957), practical geometry and engineering drawing (Smith, 1948), dentistry courses (Just, 1979), grades in art, auto mechanics and machine design (Lichert & Quasha, 1970), and college chemistry (Bowdner, Greenbowe, McMillen & McDaniel, 1983) to mention just a few of the many studies in this area.

Studies of spatial ability have almost exclusively employed paper and pencil tests. Frequently such tests do not correlate highly with each other because they measure different kinds of spatial ability (Smith, 1964) and because they are contaminated in various degrees by their susceptibility to verbal-analytical processing (Guay, McDaniel & Angelo, 1979). Reliance on paper and pencil tests to measure spatial ability has had an even more deleterious effect on research in this area: the virtual neglect of the way individuals conceptualize three-dimensional space. The purpose of this study is to describe a computer managed display designed to measure performance in a cognitively constructed three-dimensional space and to examine relationships among this component of spatial ability and other spatial tests.

Background & Related Literature

Christal (1958) found a visual imagery factor defined by three tests requiring recall of the position of stimului on a printed page. Christal pointed to the need for additional study to determine whether the imagery factor could be generalized to memory for position in three-dimensional space. Few investigators accepted Christal's challenge. Attneave and Pierce (1978) investigated the ability of people to extrapolate lines in tridimensional space by asking subjects to sit with their backs to twenty previously studied target objects. The experimenter stood in front of the subjects and pointed at various objects. The subjects' task was to extrapolate the line of the pointer into the space behind them and identify its target on each trial.

The results revealed an "impressive accuracy" in the ability of subjects to extend the pointer's line and locate objects in back of them. Equally impressive is the diversity of representational systems subjects employed in performing the task. Interviews revealed that most subjects appeared to use both modes of representation, that is, 13 of the 20 subjects described the layout of objects to themselves as verbal representations, whereas 17 of the 20 subjects reported using visual images. No clear dichotomy between "visualizers" and "verbalizers" was reported.

For subjects using imagery, interesting variations in perspective were reported. Some subjects imagined themselves in the place of the examiner, others reported seeing the objects in front of them, viewing the array from the side, or "seeing the arrays as if with eyes in the back of the head".

The Attneave and Pierce study demonstrates individual differences in the use of subjective three-dimensional space and reveals idiosyncratic features in the visualization of objects. Pinker and Kosslyn (1978) utilized a box containing suspended objects and asked subjects to commit the three-dimensional display to memory. Subjects were required to scan their mental representations and make calibrated object locations. It was found that objects situated far apart required more scanning time than objects of close proximity. These results suggest the occurrence of imagery in a three-dimensional workspace. Sarbin (1972) notes that task performance is the most useful approach for imagery research as it affords a greater degree of empirical objectivity and control for artifact. Unfortunately, there exists a paucity of performance devices that are not cumbersome and which clearly measure imagery.

It is apparent that research on mental images of spatial relationships will be facilitated by adequate measurement devices. The Wheatley Cube, a computer managed task requiring the location of an unseen dot within an enclosed space, may provide a measurement of the relevant ability. This study examines the Wheatley Cube as a possible measure of the ability to imagine a three-dimensional workspace and maintain orientation within this space.

METHOD

Thirty-three educational psychology students served as subjects for this experiment. They were administered tests of spatial/imaginal ability. Performance on these measures were then correlated with performance measures on the Wheatley Cube task. A second experiment was conducted with three new measures of spatial ability.

Instruments

The Wheatley Cube (Wheatley, 1981). This is an image of a cube displayed on a computer screen (see Figure 1).

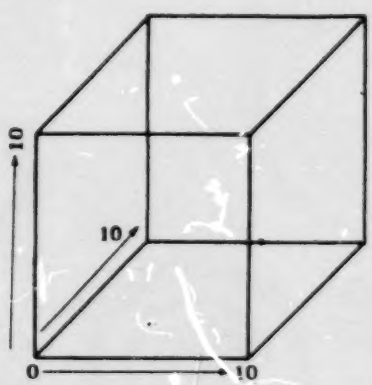

Figure 1. Wheatley Cube Schematic

The subject is informed that a dot is located somewhere within this cube and that his or her task is to discover the location of the dot. Locations are designated by specifying values on the horizontal, vertical, and front to back axes. Each axis is 10 "spaces" in length. After each attempt the computer provides feedback information by displaying to the subject the number of spaces his/her probe is from the invisible dot. This step by step process continues until the subject exhausts 12 trial probes or successfully locates the dot.

Purdue Perceptual Screening Test (McDaniel, 1974). The Perceptual Screening test is a 30 minute motion picture test composed of 25 embedded figures items and 25 items designed to measure successive processing of visual stimuli (successive figures). Separate scores are obtained for both Embedded Figures and Successive Figures. The Embedded Figures test measures the ability of the subject to discern previously shown geometric patterns from confounding geometric overlays. The Successvie Figures test measures the subject's ability to hold in memory separately presented visual stimuli and to combine them into a coherent whole.

The Cognition of Figural Transformations (CFT) (Meeker, 1975). This is a 26 item paper and pencil test which requires the subject to mentally rotate a stimulus design. The stimulus design and the multiple choice alternatives for each item are continuously in view.

The Cake. This is a perceptual problem requiring three-dimensional imagery to produce eight equal pieces of cake with three strokes of a knife. Subjects are given a drawing of a cake and instructed: "By using three cuts, create eight equal pieces of birthday cake." The CAKE Problem was scored for strategy, accuracy and time. The strategy score (1 or 2) was obtained by classifying subjects as employing trial and error strategy or a visualization strategy.

Procedure

Subjects were administered the Cognitions of Figural Transformation Test and the Purdue Perceptual Screening Test in a group session. At individual sessions subjects were administered the Wheatley Cube task followed by the Cake problem.

For the Wheatley Cube task, each subject received three trials, each trial consisting of 12 probes or chances to hit the dot. After each probe, the computer feedback indicating distance from the dot was recorded by the examiner. This information was used to calculate "Proximity" and "Slope" scores as measures of performance on the Wheatley Cube.

The proximity score was computed as follows: for each trial of 12 probes, the mean distance away from the dot of the first four probes was calculated as well as the mean distance away from the dot of the last four probes. The score for a trial was obtained by subtracting the mean of the last four probes from the mean of the first four probes. The average for the three trials was termed the proximity score. The higher the proximity score, the better the subject performed in "closing in" on the dot.

The slope score was computed as another index of performance on the Wheatley Cube. This score is the actual slope of a regression line obtained when the "error", or distance from the dot is regressed on the probe number. The slope of the regression increases as accuracy increases progressively with each probe. Conversely, if little or no progress is made in approaching the dot over the 12 probes, then the slope will be relatively flat and the index of slope will be low (Figure 2).

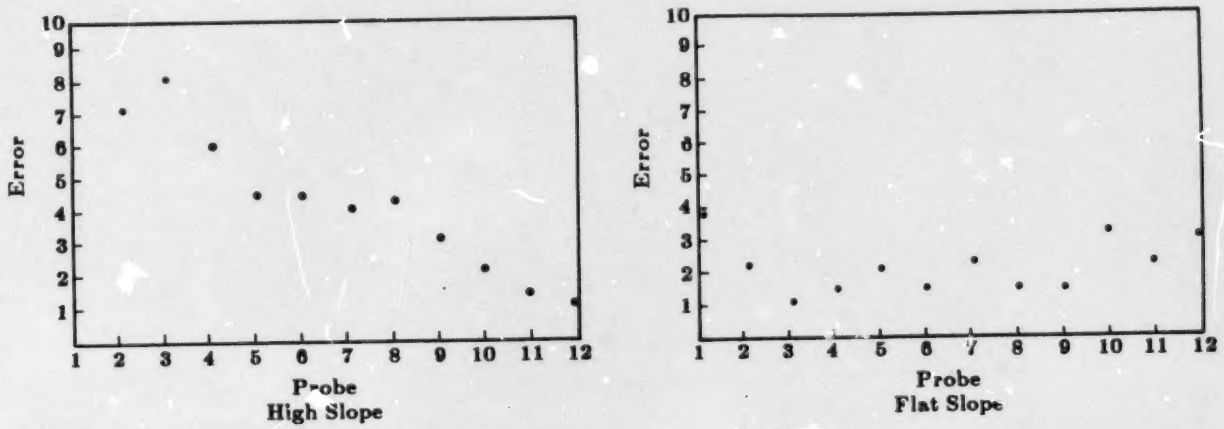

Figure 2. Regression Slopes - Wheatley Cube Performance

Subjects earned a slope score for each of the three trials (Slope 1, Slope 2, and Slope 3).

A correlation matrix was generated for the performance measures of the Wheatley Cube and the other perceptual tests.

Results and Discussion

The results are presented in Table 1, Correlations Among Wheatley Cube Performance Measures and Other Perceptual Tests.

Insert Table 1 about here

Discussion

It may be observed from Table 1 that significant correlations were obtained among performance on the Wheatley Cube and other measures of perceptual ability.

It is not clear why the Slope scores for Trial 1 and Trial 2 were not significantly related to the other indices of visualization, but it is possible that Trials 1 and 2 were "warm-up" trials in the sense that they allowed subjects to become comfortable and familiar with the task. Slope 3 represents cube performance on the third trial. Slope 3 correlated .45 (p .004) with Cognition of Figural Transformations (CFT) and .34 (p .02) with Successive Figures. The Slope 3 correlation with CFT is especially pertinent as CFT presumably measures not only the ability to visualize, but also the capacity to manipulate the visualization.

A second experiment was conducted in which the number of trials on the Wheatley Cube was increased from three to four. Three new tests were used as dependent variables: The Minnesota Paper Form Board (Lichert & Quasha, 1970), the Shepard-Metzler Rotations (Shepard & Metzler, 1971) and the Guay Rotation (Guay, 1977). The Guay Rotations test, and the Shepard-Metzler, requires subjects to rotate pictures of three-dimensional solids. These three tests were chosen for the second experiment because definite expectations could be established about the results. Guay, McDaniel, and Angelo (1978) established that the Guay Rotation Test and the Shepard-Metzler were the two tests among a group of over thirty spatial ability tests most likely to measure spatial visualization while the Minnesota Paper Form Board was the spatial measure most likely to be confounded by analytic reasoning processes. It would seem, then, that performance on the Wheatley Cube would be most highly correlated with the Guay Rotation and the Shepard-Metzler, and least highly correlated with the Minnesota Paper Form Board. All tests and the Wheatley Cube were administered to 41 students from an introductory educational psychology class.

The results only partially supported our expectations and in some instances contradicted them. The Shepard-Metzler exhibited significant correlations with Slope 1 and Slope 2, but not with Slope 3 and Slope 4. No significant correlations were observed for the Guay Rotation and the Slope scores. The Minnesota Paper Form Board was significantly correlated with Slope 4, but not with the initial three trials on the Wheatley Cube. On the whole, the inconsistency of the relationships across the four trials of the Cube are the most puzzling feature of these findings. Cooper (1982) has suggested that both qualitative and quantitative changes in cognition toward a spatial task may result from the use of differing strategies.

A re-examination of the Wheatley Cube procedure revealed three problems which may have contributed to these experimental inconsistencies. First, the location of the "hidden dot" in the cube was randomly determined by the computer program. This resulted in uneven task difficulty as the initial guess of some subjects was closer to the dot than the initial probe of other subjects. Secondly, the scales used by the subjects in specifying the location of their probes did not all originate from the same corner of the cube. The horizontal and vertical scales had the zero point located in the lower front corner of the cube, but the scale indicating depth originated in the back, lower left corner. As a result, many subjects experienced confusion during the task. Finally, the program provided 12 trials in which to locate the dot, an insufficient number of trials for many of the subjects.

The Wheatley Cube has been redesigned so that the location of the hidden dot is constant for all subjects. All scales on the cube now have a common origin, the front, lower left corner. The initial guess of the subjects is now

constrained by instructions to start in the front, lower left corner (i.e. 0, 0, 0). The number of trials has been extended to 16 for a particular presentation of the cube.

These modifications, growing out of our experience with the procedure, should contribute to the potential of the Wheatley Cube as a performance task for measuring the ability to visualize a three-dimensional space and maintain orientation within that space.

The correlations obtained thus far are promising, but difficult to interpret. First, performance on the Wheatley Cube may measure some elements of strategy in adjusting to the feedback information provided after each probe. Debriefing interviews revealed that some subjects used a visualization strategy in finding the hidden dot and others used a number processing strategy in adjusting subsequent probes. There was, however, no apparent advantage of one strategy over the other as indicated by performance scores.

A major research problem is finding ways of making explicit the construction and use of psychological space. A body of literature on cognitive mapping and spatial behavior (Downs & Stea, 1973; Moore & Colledge, 1976) holds promise for procedures which may be useful in further validation studies of the Wheatley Cube. Thorndyke and Hayes-Roth (1982) studied the learning of locations and routes under two conditions, (1) walking through an environment (navigation) and (2) studying maps of the environment (map memory). Thorndyke and Hayes-Roth found that the map memory condition led to greater internal representation of global spatial relationships than did the navigation condition. This finding suggests to us that map memory tasks may provide appropriate data for further studies of the validity of the Wheatley Cube as a performance measure of spatial visualization.

Table 1
Correlations among Wheatley Cube performance measures and other perceptual tests

	Proximity	Slope 1	Slope 2	Slope 3
Embedded Figures	.17	-.03	.16	-.10
Successive Figures	.32*	-.00	.27	.34*
Cognition of Figural Transformations	-.08	-.16	.27	.45**
Cake				
Accuracy	.16	-.09	.11	.44**
Time	-.13	.02	-.25	-.15
Strategy	.35*	-.10	.21	.31*

* = $p \leq .05$
** = $p \leq .01$

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Foctnote

We are grateful to Grayson Wheatley III for reprogramming the original Wheatley Cube to incorporate these modifications. The program is available as a diskette for either the TRS-80,I/3 Color computer or the Apple. Inquiries should be directed to Educational Programs, Inc., Box 2345, West Lafayette, IN 47906.